Verification of Star Clusters using Colour-Magnitude Diagrams (CMDs)

PAVAN VYNATHEYA
BS-MS STUDENT
IISER KOLKATA

Supervisor:
PROF. ANNAPURNI SUBRAMANIAM
PROFESSOR
INDIAN INSTITUTE OF ASTROPHYSICS
BANGALORE

1 INTRODUCTION

1.1 STARS

A star is a luminous sphere of plasma held together by its own gravity. For a major portion of its lifetime, a star shines due to thermonuclear fusion of hydrogen and helium in its core. All stars evolve, with the stages of evolution being dependent on what fuels the star. More massive stars burn faster and have more spectacular deaths (supernovae). Less massive stars live for a very long time.

Stars vary vastly in their inherent properties – mass, luminosity, surface temperature, chemical composition, etc. Knowing the mass and composition of a star, one can estimate its probable lifetime and its end stage (white dwarf/neutron star/black hole).

1.2 STAR CLUSTERS

Star clusters are a group of stars which are gravitationally bound. These stars were formed from the same Giant Molecular Cloud and hence, they have similar properties. All stars in a star cluster have same ages and similar chemical compositions (and metallicity). The only variable feature is mass.

A very useful tool in studying the evolution of a multitude of stars (and star clusters) is the Hertzsprung-Russel Diagram.

1.3 HERTZSPRUNG-RUSSEL DIAGRAM

The Hertzsprung-Russel Diagram is a scatter plot of luminosity vs. temperature of different stars *[refer Fig. 1].* The luminosity is usually represented as absolute magnitude and the temperature as spectral type (O, B, A, F, G, K, M).

The H-R diagram was developed Ejnar Herzsprung and Henry Norris Russel, and it was a very major step in helping understand evolution of stars.

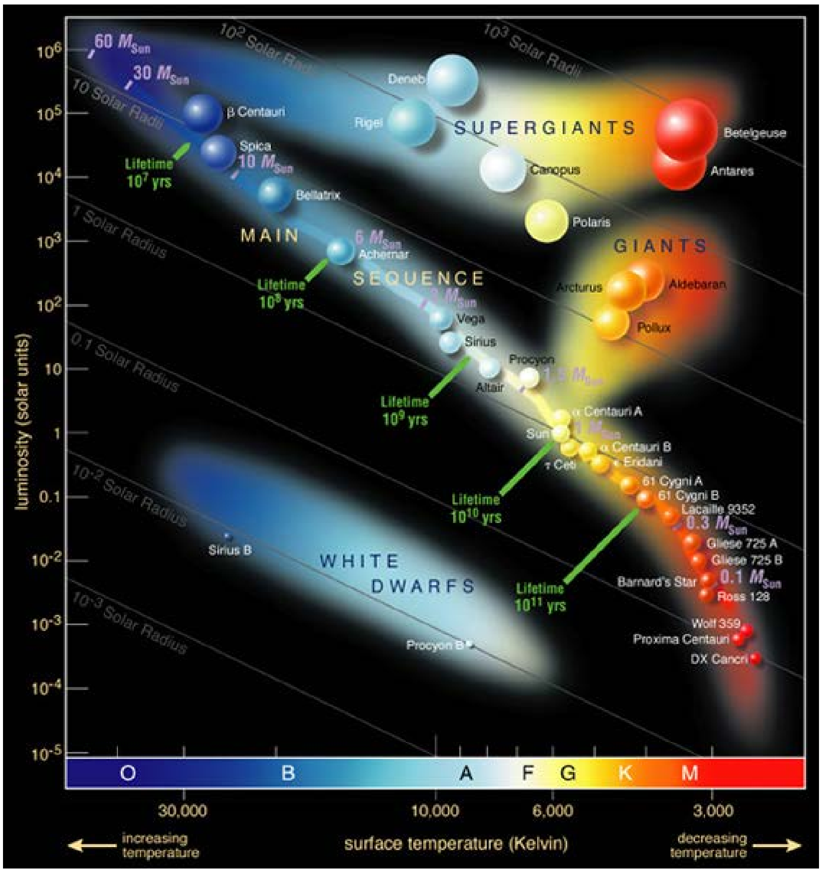


Fig 1: The H-R diagram of some stars close to the Sun. Clearly represented are the different stages of stellar evolution.

Most stars fall along a particular curve with negative slope – the Main Sequence stars. These stars are burning hydrogen in their cores. The most massive stars occupy the top-left corner (hot blue stars) while the least massive stars (cool red stars) occupy the bottom-right. The sun is somewhere in the middle.

Some stars have very high luminosities but comparatively low surface temperatures. These are the Red Giants and Supergiants. These stars have gone beyond hydrogen core burning, and are undergoing hydrogen shell burning or helium core burning or further.

Some stars have low luminosities compared to their high surface temperatures. These are White Dwarfs. These are end stages of low mass stars and have cores made up mostly carbon and heavier elements. They are also extremely dense.

1.4 Colour-Magnitude Diagram

A variant of the H-R diagram used for star clusters is the Colour-Magnitude Diagram (CMD). This plot is more direct and is more practical for observers.

In a CMD –

- Luminosity is replaced by apparent magnitude through a particular filter (in this case, the V magnitude).
- Temperature is replaced by colour index, which is the magnitude difference through two different filters (in this case, the V-I value).

1.5 Stellar Isochrone

An isochrone is a curve on the CMD (or H-R Diagram) representing a group of stars of same age i.e. it represents a star cluster *[refer Fig. 2].*

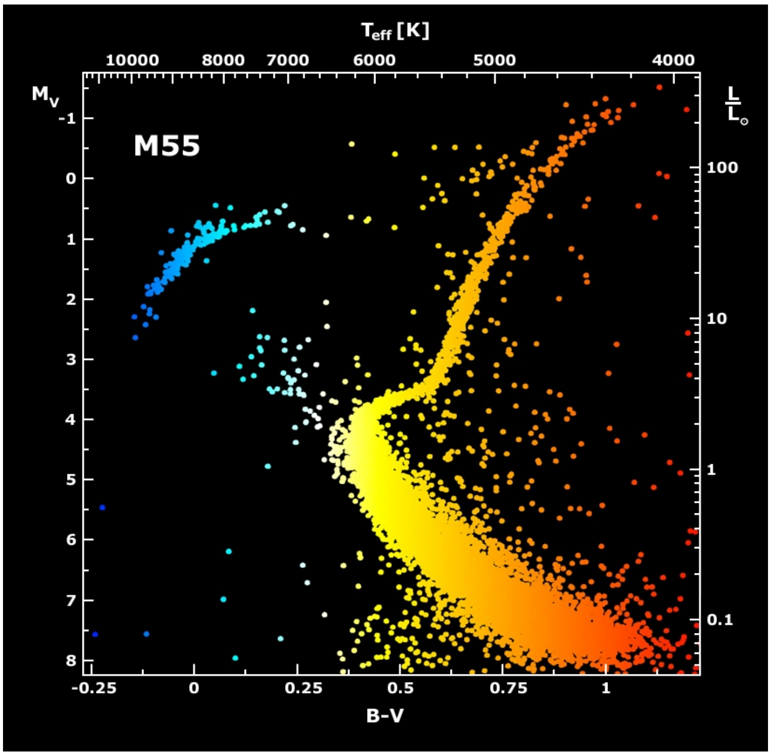


Fig 2: A typical and ideal CMD of a star cluster. Clearly illustrated are the 'turn-off point', and the Subgiant and White Dwarf branching.

Since all stars of a star cluster have same ages and are at approximately equal distance to the Earth, the CMD of all these stars is distinctive plot.

Like a CMD of any random group of stars, this plot contains a Main Sequence track, a Subgiant branch, a Red Giant/Supergiant branch and a White Dwarf region (if cluster is old enough).

Unlike a CMD of a random group of stars, that of a star cluster has a distinctive 'turn-off' point, beyond which there are no Main Sequence stars. This means that the stars more massive than the ones at the turn-off point have already evolved into giants. This gives a wonderful estimate of the age of the whole cluster. An older cluster has the turn-off point at a higher magnitude (less brightness) since more stars would have branched off to the Subgiant phase as compared to a younger one.

In older clusters, White Dwarfs are seen branching off from the Giant phase, but they are absent in younger clusters (since most low-mass stars have not fully evolved yet).

2 MY PROJECT

2.1 OBJECTIVE

To manually analyse CMDs of 212 reported star clusters in the Large Magellanic Cloud (LMC) and judge whether they are proper star clusters or not.

2.2 METHODS

A star cluster would have a CMD with most stars lying along the Main Sequence). Other stars would be along the Subgiant or Giant branch. As these clusters are young, white dwarfs are not expected.

The main features I have looked for in classification are as follows –

- Check for the Main Sequence track in the V-I index region between 0 and 0.5. This is a curve with negative slope.
- Check for a Subgiant branch in the V-I index region between 0.5 and 1. This seems to branch off from the Main Sequence.
- Check for a Red Giant/Supergiant region in the V-I index region between 1 and 1.5. This is a curve with negative slope

A cluster does not necessarily have all these specified features. For example –

- If a plot has no obvious Main Sequence track, but does have a Subgiant or Giant branch, it probably represents an old cluster (most stars are undergoing hydrogen shell burning or helium core burning i.e. they have gone past the Main Sequence).
- If a plot has stars mostly along the Main Sequence and a very few Subgiants or Giants, it probably represents a young cluster (most stars are still burning hydrogen in their cores i.e. they are Main Sequence stars).

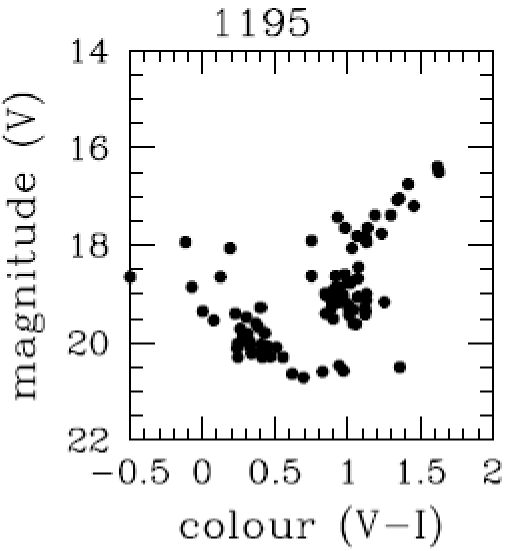
Some of the classified clusters also have no distinct Subgiant branch. Most stars fall along two distinct lines – the Main Sequences stars and the Giants.

2.3 CLASSIFICATION

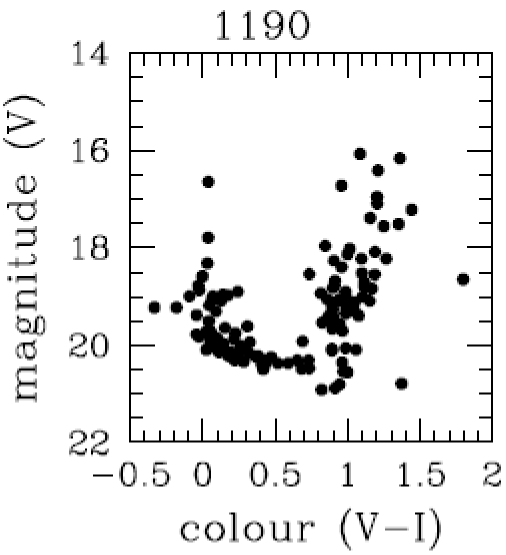
A few examples have been given for each of the three categories, namely – 'Clusters', 'Not Clusters' and 'May be Clusters'. The reasons are cited below them.

2.4 FLAGGED AS 'CLUSTERS'

Some plots which I have classified as 'Clusters' are illustrated below *[Refer file DefinitelyClusters.docx for full list].*

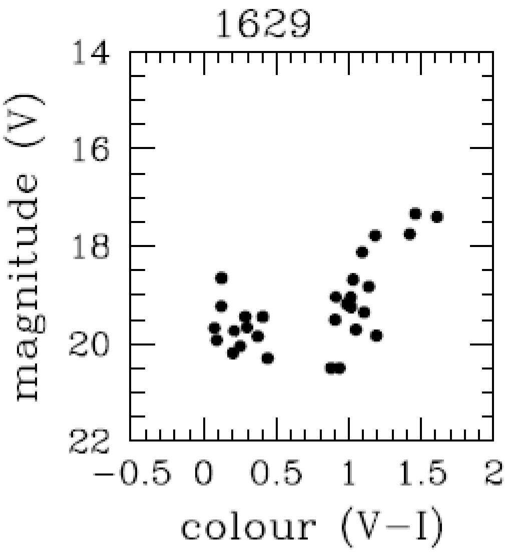


(a) BSDL456

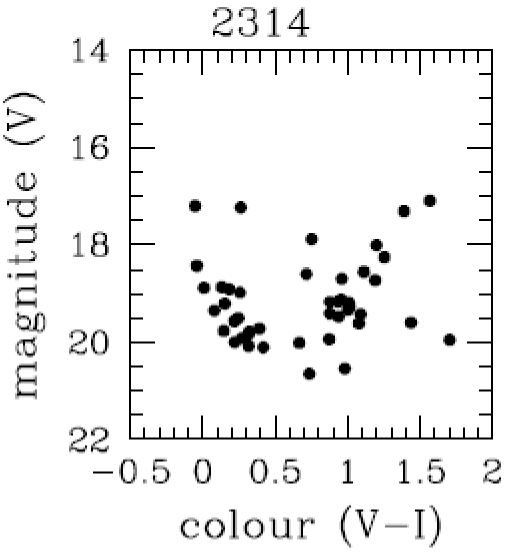


(b) LOGLE28

The plots (a) and (b) very clearly represent clusters. They have a high density of stars along the Main Sequence and an equally large number of points along the Subgiant branch.

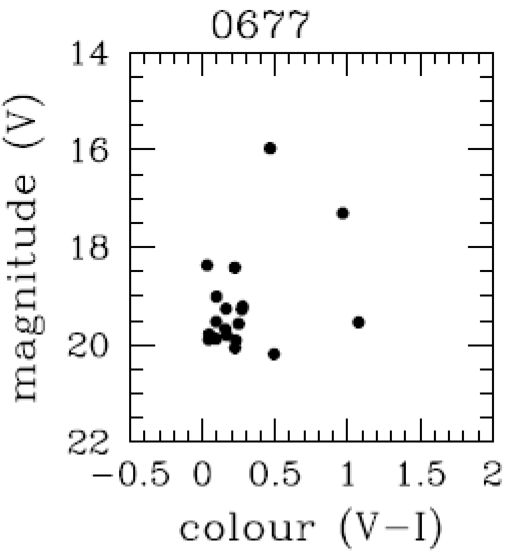


(c) BSDL852

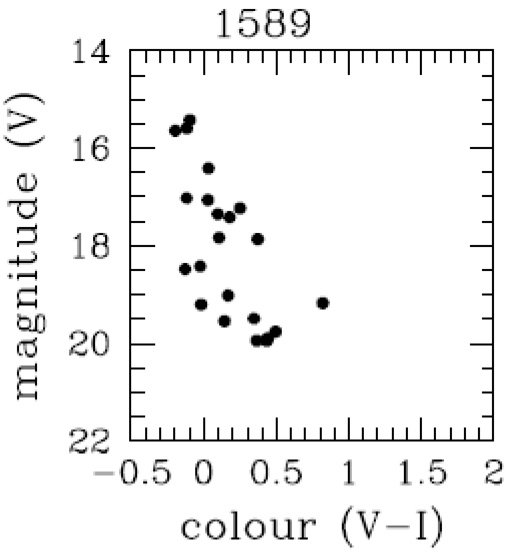


(d) LOGLE475

The plots (c) and (d) also have two distinct regions – Main Sequence and Subgiant branch. But these represent star clusters having lesser number of stars i.e. they are less dense.

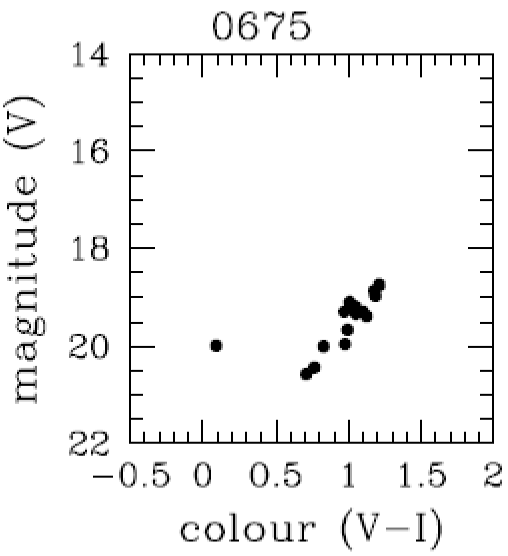


(e) BSDL3

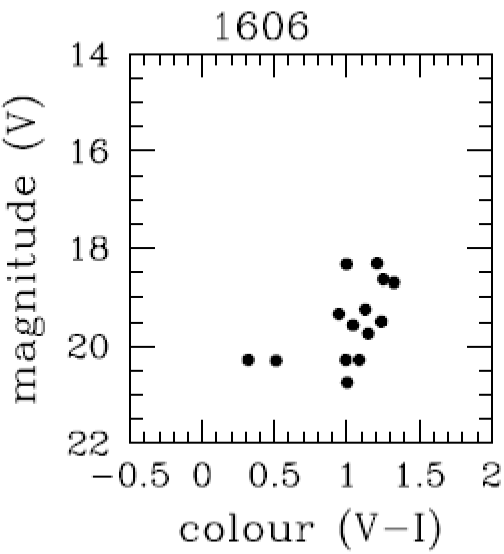


(f) LOGLE190

The plots (e) and (f) have stars concentrated along the Main Sequence only. These probably represent younger clusters, where very less stars have progressed to the Red Giant phase.

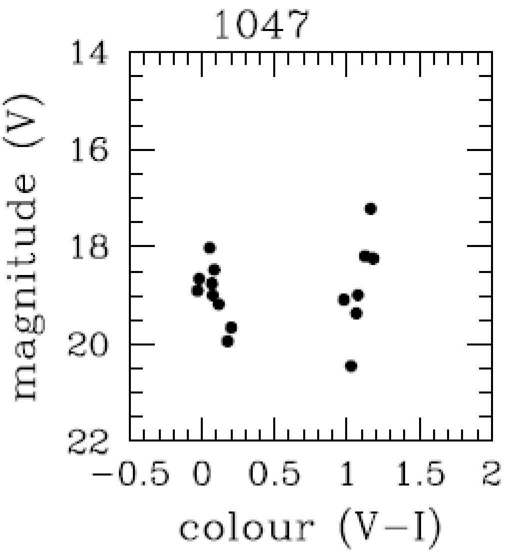


(g) LW26

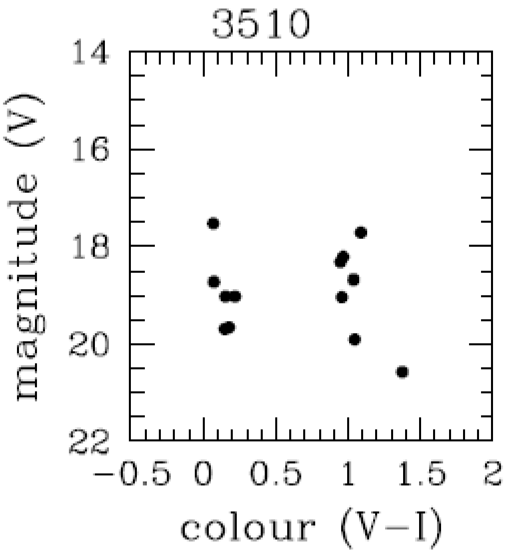


(h) HS156

The plots (g) and (h) have stars concentrated along the Subgiant and Red Giant branches only. These probably represent older clusters, where most stars have progressed to the Red Giant phase.



(i) BSDL346

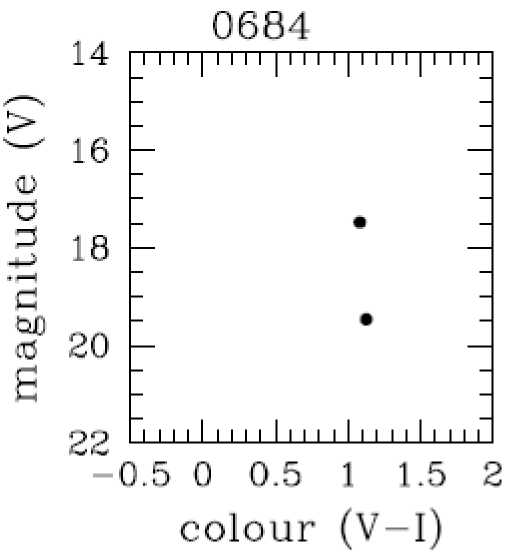


(j) KMHK1547

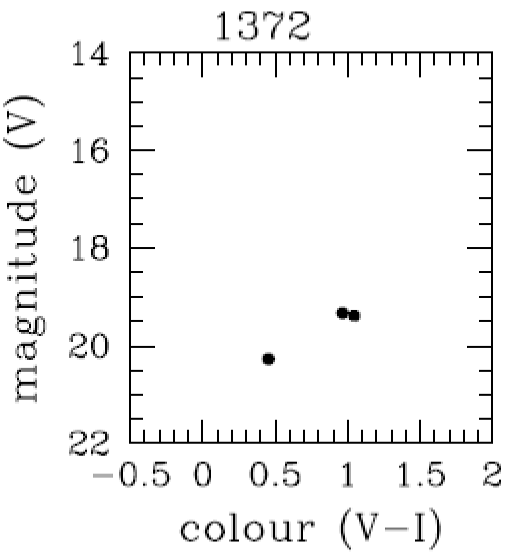
The plots (i) and (j) are not very distinct clusters. Rather than branching off from the Main Sequence, half the stars are already in the Red Giant phase. The Subgiant phase is not observed.

2.5 FLAGGED AS 'NOT CLUSTERS'

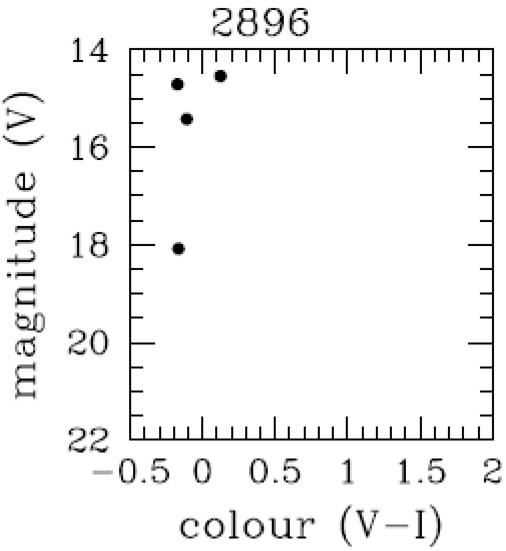
Some plots which I have classified as 'Not Clusters' are illustrated below *[Refer file NotClusters.docx for full list].*



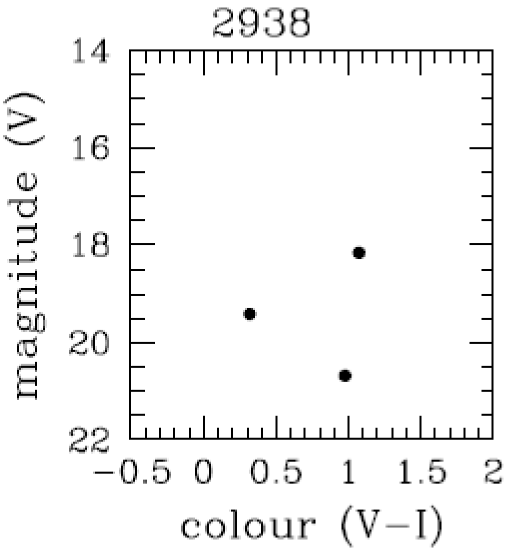
(k) LMC-S146



(l) BSDL637

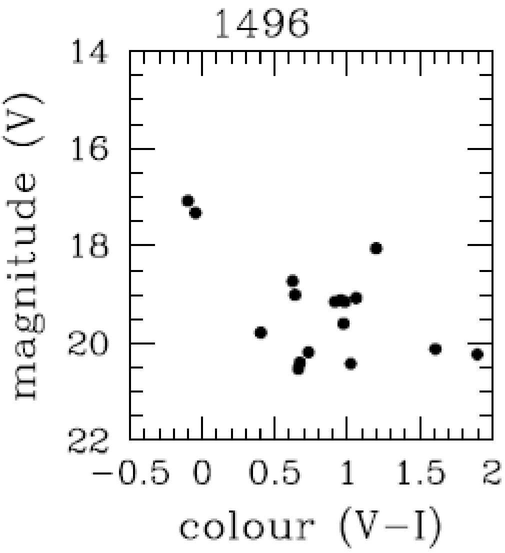


(m) WMB2

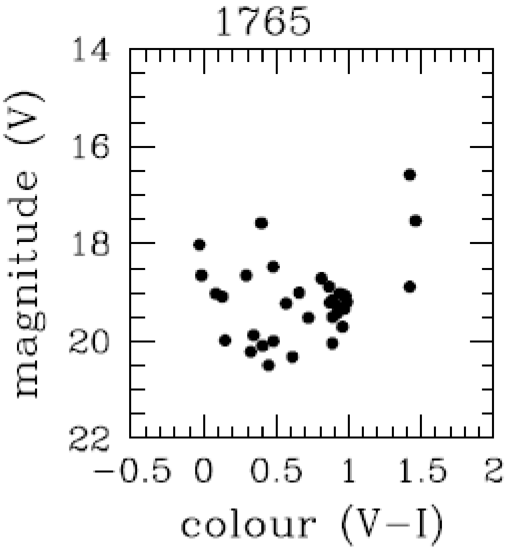


(n) NKN-N159-Y1

The plots (k), (l), (m) and (n) contain very few points (stars) to even represent a cluster. These clearly don't represent clusters (unless there is more data which has been missed).

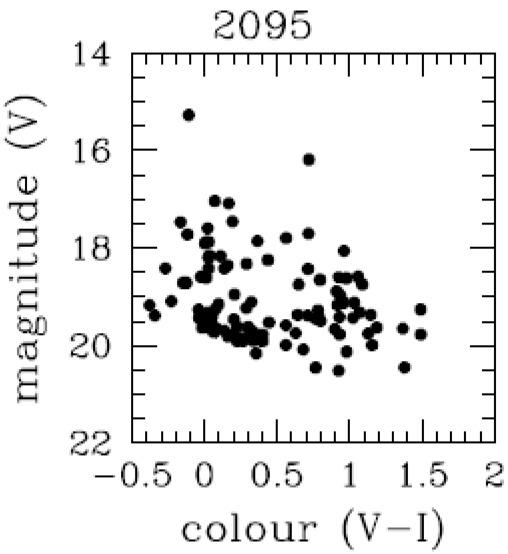


(o) LOGLE148

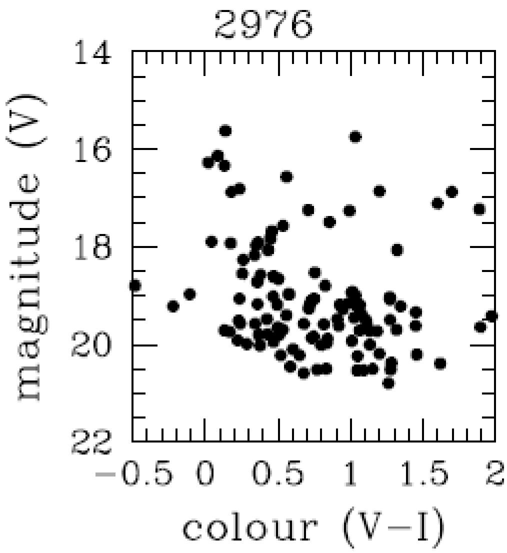


(p) LOGLE264

The plots (o) and (p) represent quite a few numbers of stars. But they don't lie along any specific fit in the plot. This fact eliminates the possibility of them being clusters.



(q) HS248

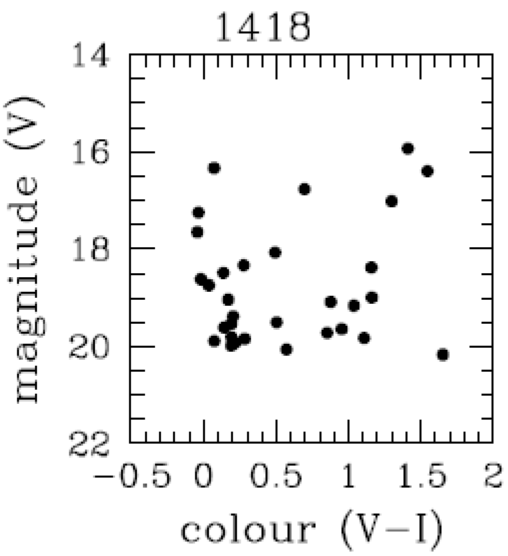


(r) NKN-N159-Y4

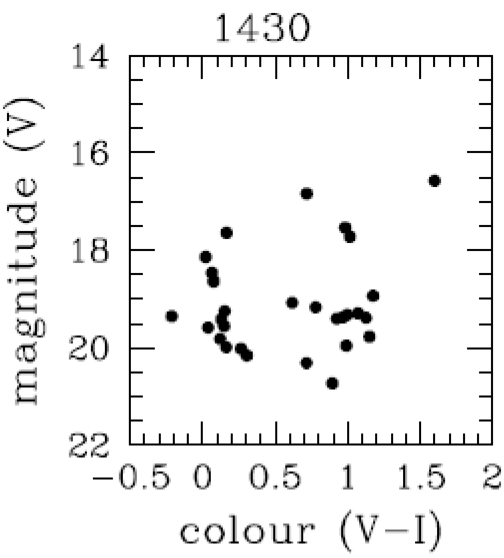
The plots (q) and (r) represent a grouping of a very large number of stars. But these don't form a cluster as they are spread haphazardly throughout the plot.

2.6 FLAGGED AS 'MAY BE CLUSTERS'

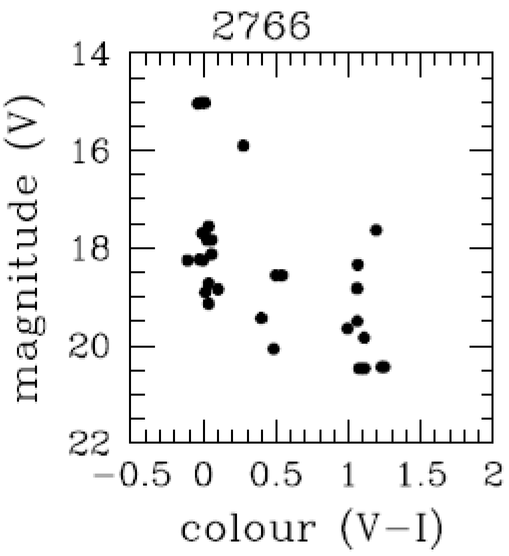
Some plots which I have classified as 'May be Clusters' are illustrated below *[Refer file MaybeClusters.docx for full list].*

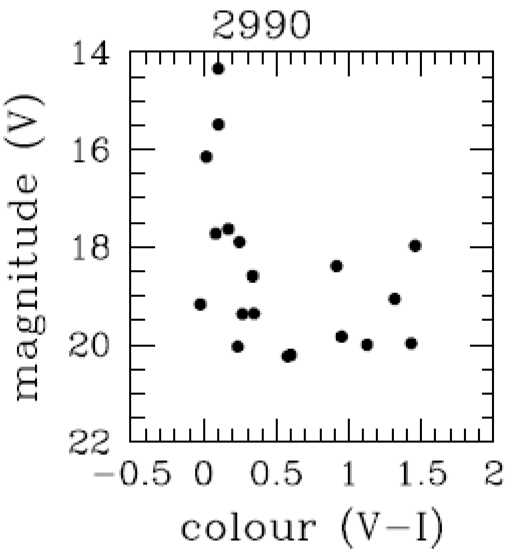


(s) KMK88-21



(t) H88-146

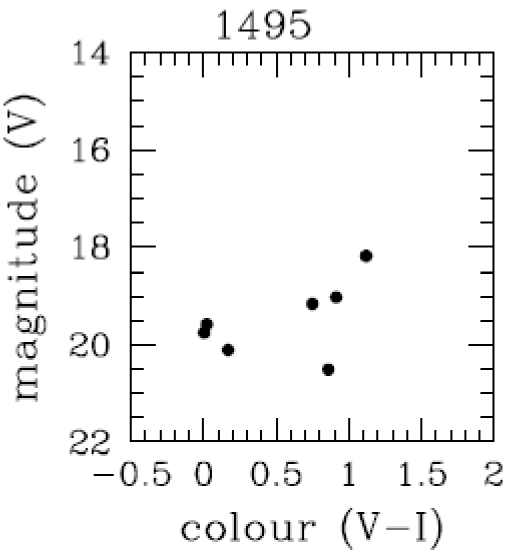


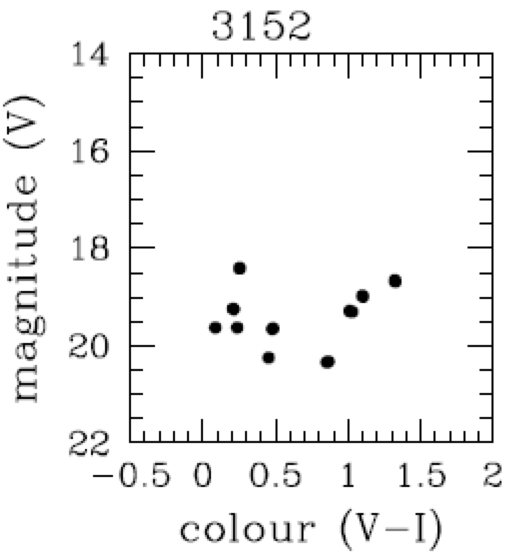


(u) KMK88-80

(v) BSDL2753

The plots (s), (t), (u) and (v) have some features of a plot of clusters. They have a distinct Main Sequence region and also a Red Giant region. But there are many more stars lying in between, which arouse doubt.





(w) BSDL715

(x) BSDL2921

The plots (w) and (x) have distinct regions of Main Sequence and Subgiant branch. But there seem to be very less number of stars. These might be small or poor clusters (or not).

2.7 RESULTS

I have flagged 98 of the plots to be proper clusters and 54 of them not to be clusters. I am doubtful about the rest of the 60 clusters (they may not be clusters or may be poor clusters).

Please refer to the files *DefinitelyClusters.docx, NotClusters.docx* and *MaybeClusters.docx* for the comprehensive list of all 212 clusters. Explanations are not given, but they may be inferred from the various examples cite above.

The 'May be Clusters' must be either promoted or denoted by further inspection, which might not be very apparent. More data would be helpful.

3 ACKNOWLEDGEMENTS

First, I would like to thank my mentor and supervisor, Dr. Annapurni Subramaniam for her support and for giving me very exciting work to do! I learnt a lot about Stellar Processes and Stellar Evolution through my project.

A hearty thank would also go to Prof. Ram Sagar, who conducted Stellar Astronomy classes for us summer interns. These classes helped me understand most of what I had to know to start my work.

Lastly, I would like to thank all my friends here and my family for providing a nice and pleasurable work environment.

Thank you.